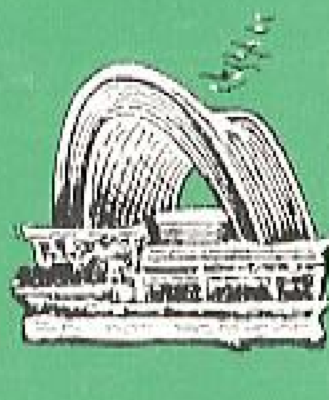
US - JAPAN JOINT REASSESSMENT OF ATOMIC BOMB RADIATION DOSIMETRY IN HIROSHIMA AND NAGASAKI

FINAL REPORT



広島

長崎

DS86

DOSIMETRY SYSTEM 1986

RADIATION EFFECTS RESEARCH FOUNDATION

VOLUME 2 (APPENDIX TO VOLUME 1)

REASSESSMENT OF
ATOMIC BOMB RADIATION DOSIMETRY

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IN HIROSHIMA AND NAGASAKI

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William C. Roesch, Editor

放影研
RERF

RADIATION EFFECTS RESEARCH FOUNDATION
A cooperative Japan - United States Research Organization

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PREFACE

Since the discovery of x rays by Roentgen in 1895, man has applied radiation to a multitude of fields. With the development of atomic energy the benefits derived from radiation have been great and they are expected to increase. No doubt radiation will continue to be an inseparable part of life.

On the other hand, radiation exposure causes deleterious effects, and with the increasing association of man with radiation, these radiation effects cannot be ignored. It is therefore an urgent task for us to clearly define these effects. In this regard, studies being made on survivors exposed to atomic bomb radiation in Hiroshima and Nagasaki have provided the most valuable data.

In 1947 the US National Academy of Sciences established the Atomic Bomb Casualty Commission (ABCC) in Hiroshima and Nagasaki to commence this important research which ABCC continued until, in 1975, ABCC became the Radiation Effects Research Foundation (RERF), a joint United States-Japan research organization.

One of the most fundamental parameters in these studies is the individual radiation dose received by the A-bomb survivors. The estimation of radiation dose was difficult because of the paucity of detailed exposure data at the time, due to the state of confusion that existed immediately following the close of the war. However ABCC, the US Oak Ridge National Laboratory, and the Japanese National Institute of Radiological Sciences were involved in developing a dosimetry system called the Tentative 1965 Dose (T65D) for use in estimating individual doses. This system was formulated on the basis of data obtained at A-bomb tests in Nevada, the BREN experiment, and large-scale shielding experiments. The T65D estimates have been in use at ABCC and RERF in Hiroshima and Nagasaki since 1965.

However, criticism was raised regarding the precision of this computation system; consequently, dosimetry reassessment groups were established in 1981 in the United States and Japan. Working groups were created in the United States and Japan, and each group with a different assignment, expended their utmost efforts in research while mutually maintaining coordination with each other. In this endeavor a total of four joint workshops were held (two in Hiroshima and one each in Nagasaki and Pasadena) for an exchange of data and views. Thanks to the dedicated efforts of these groups, a new dosimetry system called Dosimetry System 1986 (DS86) was developed. Whereas T65D was based on experimental data, the new dosimetry system was based on the establishment of an appropriate model and on computation by the Monte Carlo method. To verify the validity of this model, various experimental data and results of new measurements as well as those made in the past in Hiroshima and Nagasaki were employed.

The DS86 dose estimates which have been developed are regarded as the best possible that can be made in view of the present scientific state of the art. The results of this work will provide estimates of radiation risk that will meet the expectation of scientists of the world, including those of the United Nations Scientific Committee on the Effects of Atomic Radiation, and the International Commission on Radiological Protection.

We wish to express our sincere appreciation to the Radiation Effects Research Foundation for the work and effort which have made possible the expeditious publication of this report, and to Dr. Itsuzo Shigematsu (Chairman), Dr. Charles W. Edington (Vice-Chairman), and members of the RERF Dosimetry Taskforce for their great help and cooperation. In particular we want to express our appreciation to Mr. Geoffrey Day for his professional assistance in the production of this report, to Mr. Mitsugu Usagawa for editorial help, and to Mrs. Mioko Miyasaki and Mrs. Reiko Sasaki for their skill in typesetting the texts.

We also wish to acknowledge with gratitude the work of Dr. William C. Roesch, editor, and all of the authors and contributors who have made this report possible.

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EDITOR'S NOTE

Several special terms are common in atomic bomb dosimetry. The *epicenter* (or *burst point*) is the point in space where the bomb exploded. Bombs are large objects so they do not properly constitute a "point"; but, for dosimetry at the Japanese cities, the survivors were so far from the epicenter that the bomb can be treated as a point with good accuracy. The *hypocenter* is the point on the earth's surface immediately below the epicenter. The *height of burst* is the distance between the epicenter and the hypocenter; the *slant range* is the distance from a point to the epicenter; the *ground range* is the distance from a point to the hypocenter. At Hiroshima, where the ground is quite flat, and for much of Nagasaki, for points on the ground these distances can be treated as the sides of a right triangle, thus:

$$(\text{slant range})^2 = (\text{ground range})^2 + (\text{height of burst})^2 \qquad (1)$$

Nagasaki has more hills, however, and sometimes, this simple equation is not accurate enough (see Chapter 7).

Some of the work described in this report was done as much as 40 years ago. In the meantime, the names and definitions of the quantities and units used in the radiological sciences have undergone many changes. The older ideas will be related to the modern definitions and terminology of the International Commission on Radiological Units and Measurements (ICRU)[1] and the newer ideas will be used where possible. The final results of the new dosimetry system (DS86) will use the units of the International System of Units (SI).[1,2]

The object of the reassessment program is to determine the *absorbed dose* (or simply the *dose*) in certain organs of the people exposed to the bombs. For practicality, determination of a quantity often approximately equal to the dose, the *kerma,* is usually made instead. The concept of absorbed dose deals with the energy imparted by ionizing radiation to a medium per unit mass. "Energy imparted" means the difference in energy of the particles and quanta entering and leaving a small test volume. For the particles and quanta encountered in A-bomb dosimetry, the energy difference for photons and neutrons equals the energy they give to the charged particles they produce by interactions in the volume. This difference, per unit mass, is the quantity called the kerma. The remainder of the energy imparted is absorbed from charged particles: electrons, protons, and alpha particles. Under circumstances known as *charged-particle equilibrium* the total energy of the particles entering a small mass equals that of those leaving. In other words, they suffer no net loss of energy. The absorbed dose, therefore, equals just the kerma (neglecting a small energy loss to bremsstrahlung). "No net loss" does not mean that the charged particles do not deposit any energy in the material; it means that in the complex interplay of photons, neutrons, and charged particles, the photons and neutrons make up the energy losses of the particles. A complete explanation of this balancing (and of what to do about rest-mass changes, not mentioned in this brief discussion) and of the conditions for charged-particle equilibrium was reported by W. C. Roesch in 1968.[3]

The conditions for charged-particle equilibrium are met approximately in most of the organs of interest in A-bomb dosimetry, (i.e., the kerma gives a sufficiently accurate approximation to the dose). One organ where the conditions are not met, in general, is the skin. To calculate dose to the skin would require a special and expensive computer calculation, not justified by the limited use it would have received in the RERF studies. The present report, therefore, does not deal with dose to the skin. Neither are these conditions met in and around bone. Because radiation-induced leukemia is related to the dose to bone marrow, the lack of charged-particle equilibrium in marrow is dealt with separately in Chapter 8 and Appendix 8-4.

Kerma can be calculated in terms of the number per unit area (fluence) and energies of the photons and neutrons. Thus, given the fluences and energies at a point in any material, one can determine the kerma that the same radiations would produce in another material. This possibility is widely employed.

For example, in this report, it is common to determine the kerma that would be produced in tissue by the radiations at a point in air. One such condition is used so often that its kerma is given a special name: the kerma-in-tissue at a point in air over bare ground (i.e. no person present and not in or near a building) is called the *free-in-air (FIA) kerma* or the *free-field kerma*. The transport methods described in Chapter 3 give the fluences from which the free-field kerma can be calculated; the attenuation in buildings or people's bodies are dealt with in Chapters 7 and 8.

Another example is the use of methods for measuring *exposure* and converting the result to kerma-in-tissue (done, for historical reasons, only for photons). In A-bomb dosimetry, the value of the exposure in roentgens is approximately equal to the value of the kerma-in-tissue in rad.

References

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3. Roesch, W. C., 1968. Mathematical theory of radiation fields. In *Radiation Dosimetry*, Vol. I, Chap. 5. New York: Academic Press. pp 229-274.

CONTENTS

CHAPTER 5. MEASUREMENTS OF NEUTRON FLUENCES